

CLAIMS

What is claimed is:

1. A sensor for measuring angular velocity in a sensing plane, the sensor comprising:
 - a) a sensing subassembly comprising:
 - i) a substantially planar frame parallel to said plane; and
 - ii) a linkage connected to and within said frame and comprising a first mass and a second mass laterally disposed in said plane and constrained to move in opposite directions perpendicular to said plane;
 - b) an actuator for driving a first portion of said subassembly into oscillation at a drive frequency; and
 - c) a transducer for sensing motion of a second portion of said subassembly responsive to said angular velocity.
2. The sensor of claim 1, wherein said actuator is selected from the group consisting of electrostatic actuators, electromagnetic actuators, piezoelectric actuators, and thermal actuators.
3. The sensor of claim 1, wherein said transducer is selected from the group consisting of capacitive sensors, electromagnetic sensors, piezoelectric sensors, and piezoresistive sensors.
4. The sensor of claim 1, wherein said first portion of said subassembly is said linkage and said second portion of said subassembly is said frame.

5. The sensor of claim 4, wherein said actuator comprises an electrostatic actuator connected to said linkage, and wherein said transducer comprises a capacitive sensor connected to said frame.
6. The sensor of claim 1, wherein said first portion of said subassembly is said frame and said second portion of said subassembly is said linkage.
7. The sensor of claim 6, wherein said actuator comprises an electrostatic actuator connected to said frame, and wherein said transducer comprises a capacitive sensor connected to said linkage.
8. The sensor of claim 1, wherein motion of said frame is substantially constrained to rotation about an axis perpendicular to said sensor plane.
9. The sensor of claim 8, wherein said frame is substantially circular.
10. The sensor of claim 1, wherein said frame is substantially rectangular.
11. The sensor of claim 1, wherein said first and second masses are constrained to move only substantially perpendicular to said sensor plane, relative to said frame.
12. The sensor of claim 1, further comprising a hole in at least one of said masses to reduce air resistance.

13. The sensor of claim 1, wherein said linkage further comprises:

a center plate connected to said frame and connected to and in between said first and second masses;

a first edge plate connected to said frame and to said first mass; and

a second edge plate connected to said frame and to said second mass;

wherein said plates are rotatable about parallel axes of rotation which are also parallel to said sensor plane.

14. The sensor of claim 13, wherein said center plate further comprises a first lever arm connected to said first mass and a second lever arm connected to said second mass, whereby motion of said masses perpendicular to said sensor plane responsive to rotation of said center plate is increased.

15. The sensor of claim 13, wherein said first edge plate further comprises a lever arm connected to said first mass, whereby motion of said first mass perpendicular to said sensor plane responsive to rotation of said first edge plate is increased.

16. The sensor of claim 13, wherein said second edge plate further comprises a lever arm connected to said second mass, whereby motion of said second mass perpendicular to said sensor plane responsive to rotation of said second edge plate is increased.

17. The sensor of claim 1, wherein said frame has a fundamental frame resonant mode having angular rotation of said frame about an axis perpendicular to said sensor plane.
18. The sensor of claim 1, wherein said linkage has a fundamental linkage resonant mode having oscillation of said first and second masses, substantially 180 degrees out of phase with respect to each other, in a direction perpendicular to said sensor plane.
19. The sensor of claim 18, wherein said frame has a fundamental frame resonant mode having angular rotation of said frame about an axis perpendicular to said sensor plane.
20. The sensor of claim 19, wherein said frame resonant mode has a higher frequency than a frequency of said linkage resonant mode.
21. The sensor of claim 18, wherein a frequency of said linkage resonant mode is about equal to said drive frequency.
22. The sensor of claim 1, further comprising a substantially planar base parallel to and positioned around said frame.
23. The sensor of claim 22, further comprising a plurality of flexures connecting said base to said frame such that

said frame is rotatable about an axis perpendicular to said sensor plane.

24. The sensor of claim 23, further comprising a tab extending from said base which is engaged in a groove within said frame, the combination of said tab and said groove restricting the range of motion of said frame, thereby protecting said flexures.

25. The sensor of claim 22, further comprising a Silicon reference wafer having a top surface attached to said base, wherein said sensing subassembly and said base are etched from a single Silicon gyroscope wafer.

26. The sensor of claim 25 wherein said reference wafer comprises two recesses to accommodate motion of said first and second masses perpendicular to said sensor plane.

27. The sensor of claim 25, wherein said reference wafer comprises CMOS electronics electrically connected to said sensing subassembly.

28. The sensor of claim 25, further comprising a capacitive sensor for sensing motion of said linkage relative to said reference wafer.

29. The sensor of claim 28, wherein said linkage further comprises:

a center plate connected to said frame and connected to and in between said first and second masses;

a first edge plate connected to said frame and to said first mass; and

a second edge plate connected to said frame and to said second mass;

wherein said plates are rotatable about parallel axes of rotation which are also parallel to said sensor plane.

30. The sensor of claim 29, wherein said actuator comprises:

a first edge split electrode positioned beneath said first edge plate on said top surface of said reference wafer and separated from said first edge plate by a predetermined distance d;

a second edge split electrode positioned beneath said second edge plate on said top surface of said reference wafer and separated from said second edge plate by the distance d;

a center split electrode positioned beneath said center plate on said top surface of said reference wafer and separated from said center plate by the distance d.

31. The sensor of claim 30, wherein said electrodes are electrically driven in a cooperative manner to excite an oscillation mode of said linkage having oscillation of said first and second masses, substantially 180 degrees out of phase with respect to each other, in a direction perpendicular to said sensor plane.

32. The sensor of claim 31, wherein said drive frequency is substantially equal to a resonant frequency of said oscillation mode.

33. The sensor of claim 30, wherein said transducer comprises a capacitive sensor connected to said base and to said frame, and wherein said reference wafer comprises CMOS electronics connected to said capacitive sensor and to said electrodes, whereby wafer scale integration of said actuator and said transducer is obtained.

34. The sensor of claim 25 further comprising a plurality of flexures connecting said frame to said reference wafer such that said frame is rotatable about an axis perpendicular to said sensor plane, said flexures passing through said base and separated from said base by a plurality of base isolation trenches, whereby stress in said base is not coupled to said flexures.

35. The sensor of claim 34, further comprising a plurality of reference isolation trenches separating said top surface of said reference wafer from said flexures, whereby surface stress in said top surface of said reference wafer is substantially not coupled to said flexures.

36. The sensor of claim 25, further comprising a Silicon cap wafer having a bottom surface attached to said base.

37. The sensor of claim 36, wherein said cap wafer comprises a recess to accommodate motion of said first and second masses perpendicular to said sensor plane.

38. The sensor of claim 36, wherein said cap wafer is hermetically attached to said base, and said reference wafer is hermetically attached to said base.
39. The sensor of claim 38, wherein a gas pressure within a hermetic enclosure formed by said base, said cap wafer and said reference wafer is substantially different from atmospheric pressure.
40. The sensor of claim 38, wherein said cap wafer is hermetically attached to said base with a Si to SiO₂ fusion bond, and said reference wafer is hermetically attached to said base with a metal seal.
41. The sensor of claim 36, further comprising a plurality of flexures connecting said frame to said cap wafer such that said frame is rotatable about an axis perpendicular to said sensor plane, said flexures passing through said base and separated from said base by a plurality of base isolation trenches, whereby stress in said base is not coupled to said flexures.
42. The sensor of claim 41, further comprising a plurality of cap isolation trenches separating said bottom surface of said cap wafer from said flexures, whereby surface stress in said bottom surface of said cap wafer is substantially not coupled to said flexures.
43. The sensor of claim 42, wherein said flexures are connected to said reference wafer.

44. The sensor of claim 43, further comprising a plurality of reference isolation trenches separating said top surface of said reference wafer from said flexures, whereby surface stress in said top surface of said reference wafer is substantially not coupled to said flexures.

45. A dual-axis sensor for measuring X and Y components of angular velocity in an X-Y sensing plane, the dual-axis sensor comprising:

A) a first subsensor for measuring the X component of angular velocity, the first subsensor comprising:

a) a first sensing subassembly comprising:

i) a substantially planar first frame parallel to said plane; and

ii) a first linkage connected to said first frame and comprising a first mass and a second mass laterally disposed in said plane and constrained to move in opposite directions perpendicular to said plane;

b) a first actuator for driving a first portion of said first subassembly into oscillation at a drive frequency; and

c) a first transducer for sensing motion of a second portion of said first subassembly responsive to the X component of angular velocity; and

B) a second subsensor for measuring the Y component of angular velocity, the second subsensor comprising:

a) a second sensing subassembly comprising:

i) a substantially planar second frame parallel to said plane; and

ii) a second linkage connected to said frame and comprising a third mass and a fourth mass laterally

disposed in said plane and constrained to move in opposite directions perpendicular to said plane;

b) a second actuator for driving a first portion of said second subassembly into oscillation at a drive frequency; and

c) a second transducer for sensing motion of a second portion of said second subassembly responsive to the Y component of angular velocity.

46. A sensor for measuring angular velocity in a sensing plane, the sensor comprising:

a) a first sensing subassembly comprising:

i) a substantially planar first frame parallel to said plane; and

ii) a first linkage connected to said first frame and comprising a first mass and a second mass laterally disposed in said plane and constrained to move in opposite directions perpendicular to said plane;

b) a first actuator for driving a first portion of said first subassembly into oscillation at a drive frequency;

c) a first transducer for sensing motion of a second portion of said first subassembly responsive to said angular velocity;

d) a second sensing subassembly comprising:

i) a substantially planar second frame parallel to said plane and having substantially the same shape as said first frame; and

ii) a second linkage connected to said second frame and comprising a third mass and a fourth mass laterally disposed in said plane and constrained to move in opposite directions perpendicular to said plane, wherein said second

linkage has substantially the same configuration and orientation as said first linkage, said third mass corresponding to said first mass and said fourth mass corresponding to said second mass;

e) a second actuator for driving a first portion of said second subassembly into oscillation at a drive frequency; and

f) a second transducer for sensing motion of a second portion of said second subassembly responsive to said angular velocity;

wherein signals from said first and second transducers are combined to distinguish said motion responsive to said angular velocity from a motion not responsive to said angular velocity.

47. The sensor of claim 46, wherein said first portion of said first subassembly is said first linkage, and wherein said second portion of said first subassembly is said first frame, and wherein said first portion of said second subassembly is said second linkage, and wherein said second portion of said second subassembly is said second frame.

48. The sensor of claim 47, wherein said first and second linkages are driven such that said first mass and said third mass are driven to move in opposite directions perpendicular to said plane.

49. The sensor of claim 48, wherein said first and second frames are rotatable within said plane, and further comprising a frame linkage connecting said first frame to

said second frame, whereby said first and second frames are constrained to rotate in opposite directions.